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MOMENTUM TRANSFER AND CRATERING EFFECTS PRODUCED BY GIANT LASER PULSES

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The momentum transfer and cratering effects caused by impacts of focused laser light on surfaces of several materials were studied. As a basis of comparison with previously reported investigations, tests were made with both giant and normal laser pulses.

The giant-laser pulse contained ~ 0.3 J of energy. Its width at half maximum was 50 nsec. The targets were attached to a piezoelectric momentum transducer which was enclosed in a vacuum system at

3×10^{-5} Torr. The impulse response of the transducer was that of a slightly damped spring-mass system and a sensitivity of 1 V peak per dyn-sec.

Laser pulse energy measurements were obtained by three independent instruments: a commercial integrating photodiode calorimeter, a black-body calorimeter, and the momentum transducer. For the last method^{1,2} the momentum exchange between a defocused laser beam and a mirror was measured and the relativistic momentum equation was used

Table I. Measured Target Momenta Relative to Copper (0.18 dyn-sec). Each Pulsed Laser Focused Light Pulse was 0.3 J.

Type	Material	Relative momentum
I.	Copper	1.00
	Cold rolled steel	.94
	Tool steel	.88
	Aluminum	.94
	Brass	1.00
	Tantalum	.81
	Unglazed porcelain	.82
II.	Lead	2.00
III.	Glazed porcelain	1.70

to compute the pulse energy. Results of these three methods of measurement agreed within a factor of 2.

Table I shows the relative measured target momenta for giant laser light pulses focused on different materials. Target momenta were 0.18 dyn-sec or more and significantly exceeded the 2×10^{-4} dyn-sec predicted for total reflection of the laser quanta. Comparison of the momentum measurements and examination of the craters and of the ejected material suggested three distinct types of materials. For the first type, the ejecta were completely in the vapor state, and the momenta were nearly the same for the various materials. For the second type, lead, a number of globules of molten material were expelled along with the vapor, resulting in a higher momentum. For the third type, glazed porcelain, the laser beam evaporated material underneath the glazed surface, causing the expulsion of splinters of material and a further increase in momentum.

As expected, the target momentum was also a function of energy density. The effect of change in energy density of giant laser pulses with constant total energy has been measured for several metals by successively defocusing the spot. The result for aluminum was typical for all metals tested. For Al, as long as the average energy density exceeded 0.4 J per square millimeter, the measured momentum was essentially constant. When the energy density was reduced below this level, the momentum was approximately proportional to the square root of the energy density (e.g., at an 18-mm

spot diameter, the momentum was reduced to 0.025 of the maximum). While the target momentum should finally reach a constant value (between one and two times the light pulse momentum), minimum energy densities were limited by the target size and were too large to provide data in this regime. From the limited data, one cannot predict the change in target momentum with change in total energy or change in pulse shapes; neither can the rate of momentum decrease with decreased energy density be predicted in general.

Since most other reported experiments involving laser light interaction with solids have been performed with normal laser pulses, it was desirable to compare momenta obtained with giant pulse impacts with those obtained with normal pulse impacts. Normal laser action was obtained by deactivating the Q-spoiling Kerr cell of the giant pulse laser. Normal laser pulses consist of a large number of randomly spaced spikes occurring over an interval about a millisecond. With the same energy input to the flashlamp, the peak output power of the laser was reduced sharply while the total energy output was approximately five times that of the single giant pulse. The momentum sensitivity of the materials changed drastically when the normal laser was used. Giant and normal pulses were alternated on the same material and the ratio of the output magnitudes recorded (see Table II). A study of this table indicates that the momenta produced by normal laser pulses strongly depend on the thermal properties of the target material. For the materials tested, the momentum ratio is closely proportional to the product of the relative melting point and the thermal conductivity. Even though for most materials the target momentum due to incidence of a giant pulse was larger than that due to the normal laser pulse, the amount of material removed by the action of the giant laser pulse was always much smaller than that removed by the normal pulse, the craters being much more shallow. It appears, therefore, that the lost material is ejected with much higher velocity for giant pulse impacts than for normal laser impacts, and confirms the conclusion of Linlor.³ The reason for the greater loss of material in the case of the normal pulse was clarified as follows. A normal laser pulse focused on a revolving Al target produced a sequence of shallow holes, each similar to a crater made by a giant pulse, though somewhat smaller. The superposition of the effects in the case of a stationary target resulted in a hole with a depth of several

Table II. Ratio of Target Momenta, P , From a Giant Laser Pulsed Impact and a Normal Laser Pulse Impact. (The normal laser pulse contained five times more energy.)				
I Material (type I of table I)	II Relative thermal conductivity ^a	III Relative melting point ^a	IV Product, columns II \times III	V $\frac{P_{\text{giant}}}{P_{\text{normal}}}$ (b)
Copper	1.00	1.00	1.0	1.00
Aluminum	.48	.71	.34	.34
Tool steel	.113	1.31	.15	.22
Cold rolled steel	.113	1.31	.15	.17
Brass	.204	.89	.18	.12
Tantalum	.130	2.68	.36	.37
Unglazed porcelain	.0025	.80	.002	.04
^a Handbook values relative to copper. ^b Normalized to the ratio for Cu: $P_{\text{giant}}/P_{\text{normal}} = 0.18/0.0305 = 5.9$ (momenta in dyn-sec).				

hole diameters. Evidently the distribution of the energy over several component pulses occurring over a relatively long time interval caused more energy to be used for melting and less for evaporation of target material.

To develop a theory on laser pulse impacts, more parameters than the impact momentum must be known. Two other studies^{3,4} involving giant-pulse lasers indicate the types of measurements that should be used simultaneously with momentum and mass-loss measurements in future studies. Together they would provide data relating to the space, time, and energy distribution of the ejecta, would give some basis for defining the ratio of

ionized to non-ionized ejecta, and would therefore provide a means for calculating the efficiency of converting the pulse energy into kinetic energy.

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¹George E. Henry, *Sci. Am.* (June 1957).

²J. J. Cook and others, *Univ. of Michigan, Inst. of Science and Tech., Information Note 2900-350-1, May 1962* (unpublished).

³William L. Linlor, *Appl. Phys. Letters* 3, 11 (1963).

⁴J. F. Ready, *Appl. Phys. Letters* 3, 1 (1963).